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Characterization of InTlSb/InSb Grown by Low Pressure Metalorganic Chemical Vapor Deposition on GaAs Substrate

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Optical properties of InTlSb, a new long wavelength infrared material, are investigated. InTlSb/InSb epilayers grown by low-pressure metalorganic chemical vapor deposition on semi-insulating GaAs substrates were characterized using Auger electron spectroscopy and Fourier transform infrared spectroscopy. Auger electron spectra confirm the presence of Thallium. Transmission measurements at 77K indicate an absorption shift from 5.5μm for InSb up to 8μm for InTlSb, which is confirmed by photoconductivity measurements.

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Recent studies proposed InTlSb as a promising long wavelength infrared material[1,2]. Theoretical calculations predicted InTlSb to exhibit a stable region of zinc blende lattice for Tl concentrations up to 20 % and be lattice matched to InSb to within 2 %. $In_{1-x}Tl_xSb$ is estimated to have a bandgap of 100 meV at x = 0.09, which is within the theoretical Tl miscibility limit in InSb[1]. Compared to the HgCdTe standard II-VI compound, InTlSb is expected to offer the advantages that are common to III-V compounds: stronger covalent bonding resulting in stronger mechanical strength, better thermal stability, easier doping control, and compatibility with GaAs-based electronics. Very recently, successful growth of InTlSb on GaAs substrate by low-pressure metalorganic chemical vapor deposition (LP-MOCVD) has been reported[2]. Here we present further evidence of Thallium incorporation based on Auger electron spectroscopy, and we investigate InTlSb optical properties by means of optical transmission and of photoconductivity measurements.

Epilayers have been grown on semi-insulating superclean GaAs substrate. Trimethylindium and trimethylantimony were used as sources for In and Sb, respectively and cyclopentadienylthallium was used as the source for Tl. Detailed growth conditions have been published elsewhere[2,3]. An InTlSb layer was grown on top of an InSb buffer layer. Each layer was grown for one hour. A thick InSb epilayer that was grown for two hours has been used for comparison. Both samples had about the same total thickness (3μm), as determined from ball-polishing measurements. In order to evidence Tl incorporation, Auger electron spectra were measured and are shown in figure 1 for the InTlSb/InSb and the InSb samples, respectively. A clear peak corresponding to Tl is observed for the InTlSb/InSb sample, confirming the presence of Tl.

A Mattson Fourier Transform Infrared (FTIR) spectrometer was used to measure the optical transmission of the two samples. Figure 2 shows the experimental spectra at 77K and 300 K. The InTlSb/InSb sample exhibits a shift of the absorption edge towards longer wavelengths compared to InSb. However, conclusive assessment of the bandgap shift is difficult because of Fabry-Perot oscillations. These oscillations are produced by multiple reflections at the air-InSb and GaAs-InSb

interfaces. The period of the oscillations yields the phase shift for light passing through the epilayer, from which the product $n \cdot d$ can be extracted, where n is the refractive index of the epilayer, and d is its thickness. Let us consider the InSb sample first: assuming tabulated values for the refractive index of InSb, $n=3.9\pm0.1$ within the wavelength range of interest[4], this provides an independent estimate of the epilayer thickness, $d=2.9\pm0.1\mu$m which is about the same as the value determined from ball-polishing measurement. Looking at the InTlSb/InSb spectrum, it appears that the product $n \cdot d$ (actually, the sum of the individual products $n \cdot d$ for each layer) is slightly larger than for the InSb sample. No refractive index data is available for InTlSb, but since it has a smaller bandgap than InSb its refractive index should be higher. However, this difference is expected to be only slight compared to the large refractive index difference between InSb and GaAs. This is confirmed by the fact that no additional interference feature that might occur from the InSb/InTlSb interface is observed. In brief, the slightly higher value of the product $n \cdot d$ can originate from a slight increase in the refractive index as well as from a slight difference in total epilayer thickness that would lie within the ball-polishing measurement uncertainty.

A careful observation of figure 2 reveals that the product $n \cdot d$ increases with temperature because the fringe spacing is slightly reduced. By recording precisely the position of the Fabry-Perot extrema and their shift with temperature, we were able to determine experimentally the average value of the temperature coefficient of the product $n \cdot d$ in the transparent wavelength range: $1/n \cdot d \; d(n \cdot d)/dT = 7.7 \times 10^{-5} K^{-1}$ for the InSb sample, and $2.8 \times 10^{-4} K^{-1}$ for the InTlSb/InSb sample. It is apparent from these values that the Fabry-Perot fringes undergo a much larger change with temperature in the case of the InTlSb/InSb sample. We compared these experimental values with tabulated values for InSb[4]:

$1/n \; dn/dT = 4.5 \times 10^{-5} K^{-1}$ for the temperature coefficient of the refractive index,

$1/d \; dd/dT = 0.5 \times 10^{-5} K^{-1}$ for the thermal expansion coefficient,

from which we deduce:

$1/n \cdot d \; d(n \cdot d)/dT = 1/n \; dn/dT + 1/d \; dd/dT = 5.0 \times 10^{-5} K^{-1}$.

We note that the change in the product $n \cdot d$ occurs mainly through the variation of the refractive index. Our experimental value is in reasonable agreement with the tabulated one in the case of InSb. No such tabulated data is available for InTlSb. One of the possible reasons for the much larger temperature dependence in the case of InTlSb is the enhanced refractive index dispersion near the absorption edge which results in an enhanced dispersion for its temperature coefficient as well. Since fewer fringes are visible in the case of the InTlSb/InSb sample, the experimental value has been averaged over a narrower wavelength region close to the InTlSb absorption edge.

In order to determine the absorption coefficient, we have modeled our epilayer as a conventional Fabry-Perot etalon filled with an absorbing medium. The reflection and transmission coefficient of each interface were determined using tabulated values for the refractive index of GaAs and InSb, and the refractive index of InTlSb was assumed to be the same as that of InSb. The phase shift through the epilayer was determined from the position of the experimental Fabry-Perot extrema. The resulting absorption spectra at 77K are given on figure 3: the InSb sample exhibits a sharp absorption edge at 5.5μm. The InTlSb/InSb sample exhibits overall higher absorption, and an absorption tail extending up to 8μm is observed. It should be noted that the absorption coefficient for the InSb/InTlSb bilayer is the average of the absorption coefficients of the InSb buffer layer and of the InTlSb layer, weighted by their respective thicknesses which are approximately equal here. This tends to attenuate any feature of the InTlSb absorption spectrum, and the observed shift should be even more apparent for a thick InTlSb epilayer.

In order to confirm this bandgap shift, we have performed photoconductivity measurements on Hall patterns that have been contacted with In-Sn. Active areas were approximately 10mm². The resistance of the InSb and InTlSb/InSb photoconductors were respectively 40Ω and 100Ω at 300K, and raised to 4.8kΩ and 1.0kΩ at 77K. The photoconductivity measurements were performed using the FTIR spectrometer and were corrected for the frequency response of the internal pyroelectric detector. Photoconductor bias was varied between 2V and 10V. The dependence of the photoresponse magnitude with bias was sublinear at 300K and exhibited a maximum around 7V at 77K. This is due to photoconductor heating because of poor heatsinking

and such behavior is observed as well in HgCdTe photoconductors[5]. The magnitude of the photoconductive response was lower for the InTlSb/InSb sample. The spectral shape of the photoconductive response was independent of bias, and the normalized results are given on figure 4. The room-temperature photoconductive response spectrum of the InSb sample reveals a sharp absorption edge around 7μm. The spectrum of the InTlSb/InSb sample is noisier, which makes accurate determination of its absorption edge difficult. At low-temperature, signal-to-noise ratio was much higher, as expected, and a comparison of the normalized photoconductive response spectra for the two samples shows a clear shift of the absorption edge from 5.5μm up to 8 μm wavelength. This confirms our optical transmission measurements. The narrow feature around 4.2 μm wavelength is due to absorption by carbon dioxide in the sample compartment and can be eliminated by proper nitrogen purge. The broader feature around 3 μm wavelength is attributed to some electrical resonance within the experimental set-up, because its magnitude depended on the quality of the electrical connections.

In summary, the incorporation of Thallium has been confirmed from Auger electron spectra. Optical transmission spectra of InTlSb/InSb clearly demonstrate a shift in the absorption edge towards longer wavelengths when compared to InSb. Further analysis of transmission spectra at different temperatures suggests a greater refractive index dependence on temperature for InTlSb than InSb. Photoconductivity measurements have been performed at 300K and 77K. The low-temperature photoconductive response spectra clearly confirm the shift in the absorption edge.

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FIGURE CAPTIONS

Figure 1: Auger Electron Spectra of the InSb sample (top) and of the InTlSb/InSb sample (bottom).

Figure 2: Optical transmission of the epitaxial layers versus inverse wavelength at 77K and 300K (top: InSb sample, bottom: InTlSb/InSb sample).

Figure 3: Optical absorption spectra at 77K extracted from transmission measurements.

Figure 4: Normalized photoconductive spectral response (top: 300K, bottom: 77K).